RESEARCH DEPARTMENT

FURTHER CONSIDERATION OF THE PRINCIPLES OF STANDARDISATION OF THE FREQUENCY CHARACTERISTIC IN MAGNETIC RECORDING

Report No. C-088

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1. HISTORICAL INTRODUCTION

Standardisation of the frequency characteristic in magnetic tape recording has been discussed previously in various documents[1] and papers[2,3]. The measuring methods described therein have formed the basis of the present standardisation procedure which has been accepted by C.C.I.R. The relevant "Standards of Sound Recording for the International Exchange of Programmes" and the methods for calibrating machines to conform to these standards are set out in the "Documents of the VIIth Plenary Assembly, London 1953". The frequency characteristic standard is there specified with reference to a "standard replay chain" which involves the concept of an "ideal reproducing head", the latter being defined as a ferromagnetic reproducing head, the losses of which are negligible. The broad principle of standardisation is that all tapes should be recorded with such a characteristic that a flat overall response, within agreed tolerances, is obtained on reproduction through a standard replay chain. In practice the standard, or other known replay chain, is used to measure the recording characteristic on the tape in terms of surface induction which, in this context, means the flux density at right angles to the surface of the tape. In a perfect recording system the surface induction on the tape rises with frequency at 6 dB/octave when a constant current, I, is fed to the recording head at each frequency. The fundamental property of the ideal reproducing head is that its output voltage, E is proportional to surface induction, B_y, i.e. the quantity E/B_y is constant. The overall response of a perfect system then rises at 6 dB/octave with frequency. The concept of an ideal reproducing head has hitherto been assumed to have partial reality in the form of high-quality conventional reproducing heads, with which the overall response at the lower frequencies, using constant current in the recording head, is generally understood to obey the 6 dB/octave law. Only in the upper parts of the frequency range has it been assumed necessary to make correction for departures from the law.

As a result of the C.C.I.R. meetings an exchange of test-tapes took place between various broadcasting organisations. B.B.C. standard tapes were prepared and distributed by Designs Department, and Research Department undertook, from time to time, check measurements of the frequency response on tapes both despatched to, and received from, other organisations. The agreement between measurements in this

country and on the Continent has been fairly good particularly at the higher audio frequencies. This exchange of test tapes may be said to have established the practicability of reasonable standardisation by the methods accepted by the C.C.I.R. VIIth Plenary Assembly.

Quite early in the exchange of test tapes, however, B.B.C. measurements indicated systematic, although not large, differences between the stated and measured characteristics in the lower frequency range on some test tapes received. It was established that these differences always existed when the lowest frequency test tones were recorded with constant current in the recording head, on the assumption that this would provide a surface induction rising at 6 dB/octave until losses in the tape or recording head became appreciable. The surface-induction/frequency characteristic then measured rose at less than 6 dB/octave at the lowest frequencies and the magnitude of the discrepancy, choosing 500 c/s as a reference, or "lining-up", point for comparison with a 6 dB/octave characteristic, was of the order of 3½ dB at 40 c/s.

This report describes various experiments carried out to ascertain the nature of the discrepancy and discusses the results and the effect which they must have, together with some other factors, on the existing formulation of the C.C.I.R. documents relating to the frequency characteristic standardisation of magnetic recordings.

2. MEASUREMENT OF LOW-FREQUENCY RESPONSE

The three methods by which the surface induction on the tape is measured for standardisation purposes are by means of a short-gap conventional reproducing head, a long-gap reproducing head and, in the laboratory, a non-magnetic conductor[1,2,3]. A description of these methods is contained in the reports and the annexe to the 1953 C.C.I.R. documents previously referred to. The non-magnetic conductor is a type of reproducing device which does not disturb the distribution of flux at the surface of the tape and it may be considered to correspond to the Buchmann-Meyer or Light-Pattern method of disk recording. The long-gap reproducing head method entails making measurements at the frequencies of successive maxima which occur in the response of such a head. The lowest frequency at which a measurement can be made is that of the first maximum in the response so that in general this method does not provide information on the surface induction at the very lowest frequencies. Below the first maximum frequency some assumption must be made as to the surface induction created by a given recording current/frequency characteristic in the recording head, e.g. it must be assumed that constant current in the recording head produces a surface induction rising with frequency at 6 dB/octave. To investigate the validity of this or any other assumption the short-gap reproducing head and the non-magnetic loop must be employed.

3. EXPERIMENTAL LOW-FREQUENCY RESULTS

3.1 Results using Short-Gap Reproducing Heads

Fig. 1 shows the divergence measured at low frequencies on three tapes, recorded with constant current in the recording head and with h.f. bias conditions

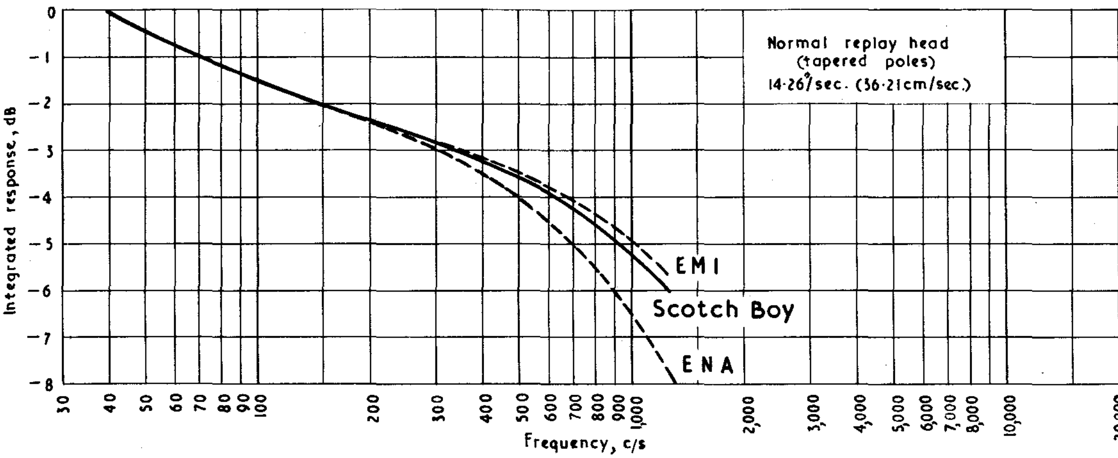

Fig. 1 - Divergence of measured overall characteristic from theoretical overall characteristic

suitable for each. The curves shown have been corrected for the 6 dB/octave rise of surface induction which would be expected, i.e. represented in this form a perfect system would have provided a level characteristic over the frequency range examined. The relative surface inductions were measured using a high-quality, narrow-gap conventional reproducing head in the manner previously described. It will be observed that there is a systematic departure from the expected "perfect" characteristic, which is approximately constant for all three tapes between 40 c/s and 300 c/s after which there is a slight difference due to their differing high-frequency properties. The E.M.I. and Scotch tapes are typical of those which would be employed for standardisation purposes whilst the E.N.A., being homogenous, is not. The divergence from the perfect characteristic can, for practical purposes, be considered constant for typical standardisation tapes measured with the same head in the range 40 - 500 c/s and it is this region and these tapes to which attention will henceforward be confined. Using the 500 c/s level as a reference point it will be observed that the divergence from the expected characteristic is of the order of 3½ dB at 40 c/s. There is some evidence to suggest that this figure, and the slope of the divergent characteristic, can be changed to some extent by increasing the depth of the pole tips of the conventional reproducing head. The matter will not be pursued here, however, except to note that it constitutes a basic uncertainty in the standard referred to a reproducing head.

3.2 Results using the Non-Magnetic Conductor Head

It is now necessary to examine the low-frequency divergence shown in Fig. 1 using the non-magnetic conductor head. The result of recording with constant current and measuring the surface induction with this head is illustrsted by Curve 1 of Fig. 2 in which, as before, the measurements have been corrected for the 6 dB/octave slope

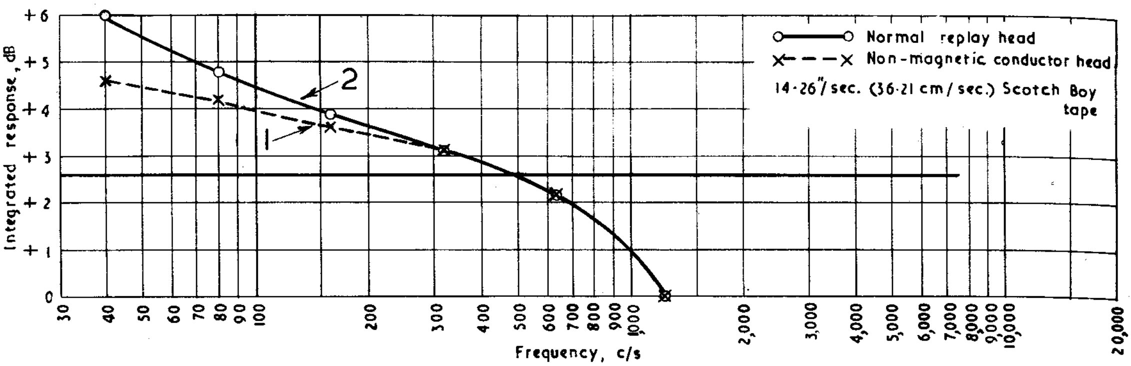

Fig. 2 - Divergence of measured overall characteristic from theoretical overall characteristic using

(1) Non-magnetic conductor head

(2) Conventional reproducing head

expected. A typical result for the conventional head is shown, as Curve 2, for comparison. The perfect system result is represented by the horizontal line which is drawn through the chosen reference point of 500 c/s. It will be observed that a divergence from the perfect characteristic is still present but this has now been reduced to some 2 dB at 40 c/s. Two interpretations of this result are possible:

(i) The non-magnetic conductor reproducing head is, itself, in error, though to a lesser degree than a conventional head.

(ii) The result provided by the non-magnetic conductor head is correct and the surface induction/frequency characteristic provided by the constant-current condition in a conventional recording head is not a 6 dB/octave characteristic.

The first possibility is discussed in the next paragraph where the argument shows that there is no evidence, and no reason, to expect the non-magnetic conductor head of suitable dimensions to be in error. The second possibility is, however, by no means unlikely. In analysing the action both of conventional recording and reproducing heads, assumptions must be made on the distribution of field in the region of the gap. It is probable that these assumptions are only partially correct so that divergence between theory and practice may be observed at the extreme ends of the frequency range. An interesting observation, in view of the principle of reciprocity which is utilised in Westmijze's recent (and more exact) analysis[4] of the reproducing head action, is that if one takes the measure of surface induction by the non-magnetic conductor to be correct the divergence observed in the conventional system is attributable to the reproducing and recording processes in roughly equal proportions.

4. THE NON-MAGNETIC CONDUCTOR HEAD

The action of the non-magnetic conductor head as a reproducing device has been analysed elsewhere[2,3]. The geometry of the device is essentially simple and the analysis is correspondingly straightforward. No assumptions need be made in this analysis other than the one, which must be made in dealing with all forms of reproducing device, that the tape being reproduced is uniformly magnetised across its width. Actually, whatever this distribution may be in practice, it is not affected by the non-magnetic conductor head. Experiments using conductors of varying cross-section in contact with the tape have been shown[2] to provide the same measure of surface induction providing that the correct relative constants are embodied in the expression defining the head output. Thus, when of suitable dimensions, the completed loop may be assumed to intercept, and hence to give an output proportional to, all the flux leaving the active side of the tape. The suitable dimensions required are illustrated by Fig. 3. Firstly, the front conductor in contact with the tape must be

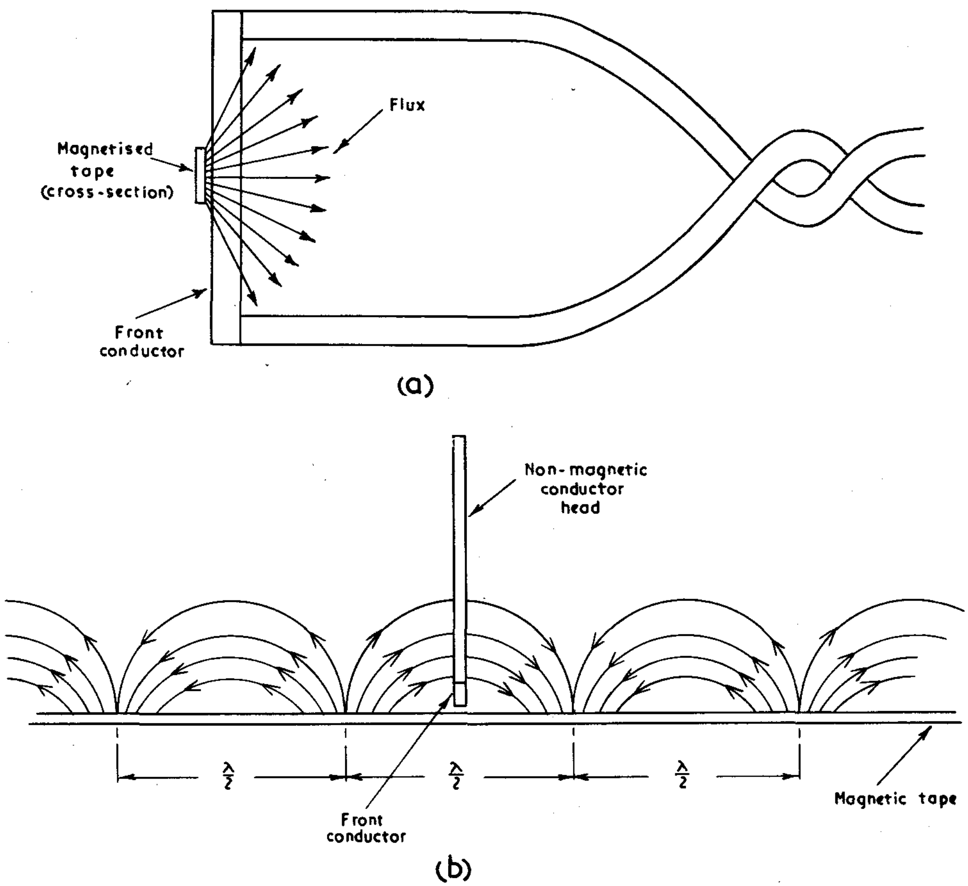

Fig. 3 - Dimensional requirements in the non-magnetic conductor head

sufficiently long (Fig. 3(a)) to intercept, for practical purposes, all the flux from the active side and, secondly, the depth of the completed loop itself (Fig. 3(b)) should be such that errors due to long-wavelength flux passing round the back of the loop, and hence inducing no useful voltage, are negligible. With these provisions

The non-magnetic conductor head may be considered to provide a reliable measure of all the flux in each recorded half-wavelength, right down to the lowest frequencies of interest. The same claims cannot, however, be made for the conventional reproducing head. Firstly, it is not possible to say what proportion of the flux from the active side of the tape at any given wavelength is drawn into the head. Secondly, the dimensions cannot be made sufficiently large, without serious inconvenience, for flux from the very longest wavelengths to be collected efficiently. Thirdly, the long-wavelength response is complicated by secondary-gap effects caused by the presence of coils and magnetic shields. In examining low-frequency phenomena, therefore, the only reliable measure must be assumed to be provided by a suitable loop head and differences from such measures given by conventional heads, must be attributed to inaccuracies in the assumptions (necessarily) made in providing a reasonable working analysis of their action.

5. SECONDARY GAPS IN THE CONVENTIONAL REPRODUCING HEAD

It might be suggested that the low-frequency divergence exhibited by the conventional reproducing head is not significant of any fundamental departure from the expected 6 dB/octave law, but is merely the result of imperfect measurement due to the occurrence of secondary maxima and minima in this range of long wavelengths. This interpretation would ignore the systematic divergence from the 6 dB/octave law which is also indicated by the non-magnetic conductor, with which no secondary "gaps" are possible. In addition, the divergence observed with the conventional head (as with the non-magnetic conductor) is always positive, i.e. the slope of the measured characteristic is always less than 6 dB. There is no reason why an error of this type should arise as a result of the observer always choosing points of maximum, and never of minimum, response in the secondary-gap characteristic. The position is illustrated by Fig. 4 which shows the low-frequency characteristic measured with a small reproducing head of the type shown in the inset to the Figure. The secondary

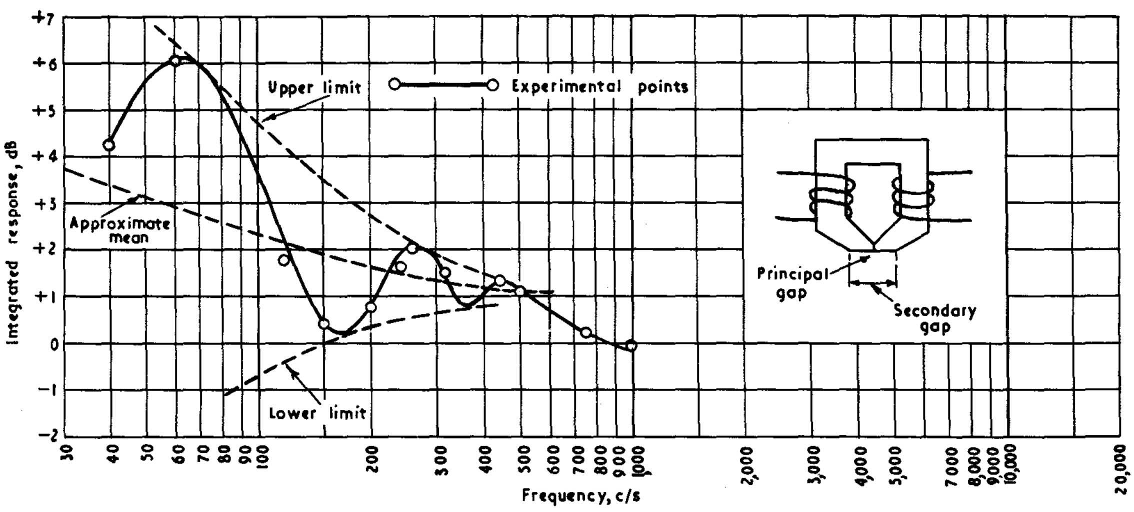

Fig. 4 - Low-frequency characteristic measured with a conventional reproducing head having a secondary gap

maxima and minima are very evident, due to a well defined secondary gap. It is clear that values could be measured to give a characteristic which sloped more or less than 6 dB/octave according to whether points of maximum or minimum response were chosen. A most important observation, however, is that the mean of the undulations provides a characteristic which lies above the "perfect" horizontal characteristic in the same manner as the smooth characteristic of better conventional heads. In this connection the recent analysis of Westmijze[4] is again of interest, which indicates that the mean of the undulations due to secondary gaps should lie on the smooth curve which would otherwise be obtained with the principal gap alone.

Another experiment was carried out to ascertain the effects, if any, which secondary maxima or minima might be having on the conventional heads used to measure the characteristics of Fig. 1. In this experiment a wide range of wavelengths was investigated by tests at two very different recording speeds, the lower one being the speed at which the characteristics of Fig. 1 were obtained. The conditions in the recording head, in terms of both recording current and range of frequency, were, however, the same at each speed. The characteristics measured at the two speeds are shown in Fig. 5. It will be observed that they can be perfectly aligned over the

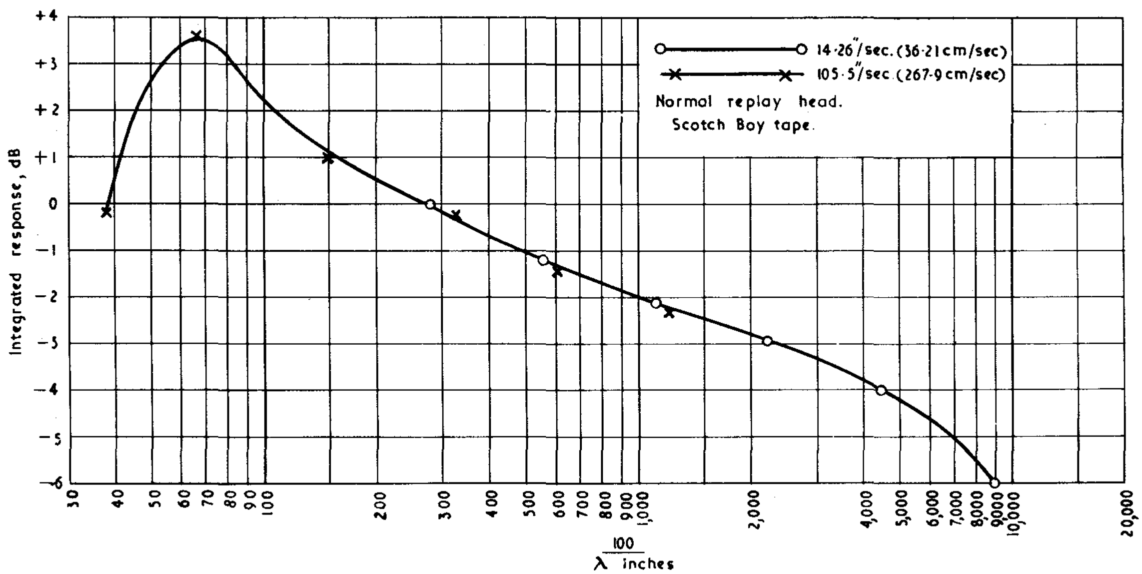

Fig. 5 - Long-wavelength response of the measuring head

common range of wavelengths and that the composite curve is smooth over the range of wavelengths of interest. The maximum observable corresponds to a frequency of about 10 c/s at the lower speed at which the characteristics of Fig. 1 were obtained. Below this the response falls away sharply as the reproducing head becomes inefficient due to it collecting a smaller proportion of the long-wave flux. It is unlikely, therefore, that secondary maxima and minima are having any influence upon the result measured with the conventional reproducing head. The divergence seems, in fact, to be fundamental to what may be called the "principal-gap" response of the reproducing head and to the recording process.

6. DISCUSSION

6.1 The Effect on Calibration Procedure

It appears from the experiments described in the previous paragraphs that in adjusting a recording channel to conform to the agreed standard,

(1) the values of surface induction must actually be measured at all frequencies, and

(2) only the non-magnetic conductor can, at present, be used for the measurements, if a primary standard is required.

It must be assumed that neither the characteristic resulting from a constant current in a recording head at low frequencies nor the performance characteristic of the ferromagnetic reproducing head at low frequencies is known with sufficient accuracy to permit conventional systems being employed for primary standardisation in this range. Existing knowledge of the performance of the high-quality conventional reproducing head seems quite adequate, however, for measurements in the middle and higher frequency ranges, as is illustrated by the close agreement of results obtained there, firstly as carried out by different organisations in the recent exchange of test tapes and, secondly, as between conductor and conventional head procedures. In the field, in fact, the short-gap conventional head may still be used with convenience to give a practical or secondary standard which will lie within the agreed tolerances over the whole frequency range if the function $\lambda/\pi d \sin \pi d/\lambda$, hitherto assumed to define its low-frequency response correctly, is taken to be in error by some 2 dB at 40 c/s falling to 0 dB error at 500 c/s. Alternatively, the secondary or practical standard may be achieved if the recording-current/low-frequency characteristic used in the recording chain is one of constant current modified to take account of the error of some 2 dB at 40 c/s falling to zero dB at 500 c/s, discussed in para. 4. Similar provisions apply to the long-gap method in which the performance of the reproducing head in the middle and higher frequency regions seems also to be known with sufficient accuracy. At very low frequencies, where the method is largely inapplicable, the alternative assumption described above must be made in respect of the recording-current/low-frequency characteristic of the normal recording head. Conventional reproducing heads with short or long gaps have then a similar utility for secondary standardisation, for both may be used with sufficient accuracy down to a frequency of some 500 c/s after which an assumption must be made, either in respect of the reproducing or recording process, to provide the low frequency characteristic. The methods described in the annexe to the C.C.I.R. VIIth Plenary Documents, which in practice have proved so successful, may be used as before, therefore, except in so far as they should be modified to take account of the anomalies and findings described here.

6.2 The Need for a Redefiniti n of the Frequency Standard

The definition of the frequency standard in terms of an "ideal" reproducing head and a "standard replay chain" depends upon one important fundamental assumption, namely, that such a chain can be created using a high-quality conventional narrow-gap reproducing head when due correction is made only for the gap and eddy-current losses in the head within the wavelength and frequency ranges of interest. The

determination of these two losses in the high-quality head does not involve any precise knowledge of the recording process. Thus to determine the effective gaplength of the head no knowledge of the slow-speed recording characteristic is required other than that it is smooth in the region where the first minima occurs so that observation of the latter is not obscured. Similarly, the eddy-current losses can be determined either by tests which do not involve recording at all or by a multispeed test which involves the recording of only one frequency at a uniform level. It is then assumed that the response of the head at low frequencies rises linearly with surface induction so that the incorporation of the higher frequency corrections, determined as above, in the reproducing amplifier circuits will make the reproducing system effectively "ideal". After this any further equalisation circuits may be incorporated, as agreed, which take account of the average magnetic properties of the types of tape being used.

It is clear, however, that over no part of the frequency range does the high-quality conventional reproducing head behave in an "ideal" manner, i.e. there is no part of the range in which the losses are negligible. Those anomalies which have been demonstrated at the low-frequency end of the spectrum cannot, at present, be satisfactorily explained. The "ideal" reproducing head can, therefore, no longer serve satisfactorily as an ultimate reference of frequency characteristic standardisation for the conception appears now to be based on an uncertain premise and a head can only be made "ideal" with knowledge of the low-frequency recording characteristic. The standard so defined is, in effect, being referred to a 6 dB/octave characteristic of surface induction and it can be so referred only through the medium of the non-magnetic conductor reproducing head, for which no fundamental errors or anomalies have, so far, been demonstrated. This procedure is illogical and is unnecessarily complicated. A possible alternative is to redefine the frequency characteristic with reference to a standard replay chain in which the reproducing device is a non-magnetic conductor. However, this would involve the definition of an "ideal" non-magnetic conductor head, the response of which could not be expressed as a simple linear characteristic unless the dimensions of the principal conductor in contact with the tape were so small that it could not be used in practice. Such a definition would be open to similar criticisms to that applying to the "ideal" reproducing head, for the standard could only be related to the response of the "ideal" non-magnetic conductor head at second-hand, through the medium of conductors of practical dimensions. It is, in fact, quite unsound to relate the frequency standard to a reproducing device at all. The quantity to which the frequency characteristic standard is related should be one which is a characteristic of the recording and which can be measured in definite terms by a practical device, in such a way that the properties of the measuring device do not appear in the final result, except in so far as questions of accuracy of the measurement may arise. Such a quantity is "surface induction on the tape" which is, at present, used in converting actual measurements to the standard related to the ideal reproducing head. The recording characteristic standard will then be measured directly by a non-magnetic conductor of suitable dimensions in a manner which leaves it, for practical purposes, unaffected by the measuring process. From this viewpoint the non-magnetic conductor method may be considered to correspond to the Buchmann Meyer or Light-Pattern Method employed in disk recording. In disk recording the standard is expressed in terms of recorded velocity on the disk, and the unreliability of the conventional reproducing device (the "pick-up") in measuring such a quantity is assumed. If the above proposals are accepted the frequency characteristic standard in magnetic recording is based on the same broad principle, for the standard is referred to surface induction on the tape,

a property of the actual recording, and it is assumed that the conventional reproducing device cannot give a reliable measure of it but, as in the disk case, a reliable laboratory method exists to measure it.

6.3. The Standardisation of Absolute Level

In considering these proposals it is also important to take note of the requirements for absolute standardisation of the recorded level which are now becoming more frequent. Clearly it would be quite impracticable to relate the standard of absolute level to any particular form of reproducing device because its properties could not be defined in relation to absolute level. The level can, however, be definitely expressed in terms of surface induction, for absolute values of this quantity can be measured by the non-magnetic conductor as described elsewhere[2, 5]. The ultimate standards and measuring methods are, therefore, identical for both the absolute level and the frequency characteristic. The form of standardisation proposed is not related to any specific measuring method or "ideal" conception and any suitable device whose properties are fully understood may be used to measure the values of surface induction in relative or absolute terms.

7. REFERENCES

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